Correct the sensor-tilt problem

by Wenshan Wang

1 Problem

The sensor tilt may cause a phase shift and value bias in the observed downwelling shortwave radiation (I). It can be corrected by (*Goswami et al.*, 2000):

$$I_h = I_t \cdot \frac{\sin\alpha + d_f}{\cos i + d_f \cdot (1+\cos\beta)/2 + \rho \cdot (\sin\alpha + d_f)(1-\cos\beta)/2} \tag{1}$$

Where,
I_h and I_t are the downwelling shortwave fluxes on the horizontal and tilted surface, separately;
α is solar altitude angle;
d_f is the ratio of diffuse solar radiation, which will be estimated from satellite observed cloud fraction;
i is the solar zenith angle observed from the tilted surface;
β is the tilt angle of the surface;
ρ is ground reflectance, which is 0.8 for snow cover;

$cos\, i$ depends on a_w (the rotated angle) and β (the tilted angle). In order to get I_h, a_w and β need to be estimated.

2 Strategy

Under clear sky conditions, when $d_f = 0.2$ (*van As*, 2011), I_h simulated by CRM with AIRS profiles can be used to estimate (a_w, β), which will be used to correct the tilt problem in this month.

3 Equations (*Goswami et al.*, 2000)

$$\cos i = \cos\alpha\, \cos(a_s - a_w)\sin\beta + \sin\alpha\, \cos\beta \tag{2}$$
$$a_s = \sin^{-1}(\cos d_s\, \sin h_s / \cos\alpha) \tag{3}$$
$$\alpha = \sin^{-1}(\sin \mathrm{lat}\, \sin d_s + \cos \mathrm{lat}\, \cos d_s\, \cos h_s) \tag{4}$$

Where,
α is the solar altitude angle;
a_s is solar azimuth angle;
d_s is solar declination;
h_s is solar hour;
lat is latitude.
d_s is calculated using *Reda and Andreas* (2004).

$$h_s = (\text{solar time} - 12:00\,\text{pm})/4 \tag{5}$$
$$\text{solar time} = \text{LST} + \text{ET} + (\text{lon}_{\text{ref}} - \text{lon}) \times 4 \tag{6}$$
$$\text{ET} = 9.87 \sin 2\text{B} - 7.53 \cos \text{B} - 1.5 \sin \text{B} \tag{7}$$
$$\text{B} = 360(n - 81)/364 \tag{8}$$
$$d_f = 0.2 + 0.8 \times \text{cf} \tag{9}$$

Where,
n is the day of the year;
LST is local standard time;
ET is equation of time;
lon is longitude;
lon_{ref} is the reference longitude of the time zone;
B is just a constant.
cf is cloud fraction from CERES.

Theoretical shortwave downwelling radiation under clear-sky conditions ($I_{h,t}$):

$$I = I_0 \cdot \left[1 + 0.034 \cos\left(\frac{360n}{365.25}\right)^{\text{o}}\right] \tag{10}$$
$$I_{h,t} = C_n \cdot I \cdot e^{-k/\sin\alpha} \cdot (d_f + \sin\alpha) \tag{11}$$

Where,
I is shortwave downwelling radiation at TOA according to my understanding;
I_0 is solar constant;
C_n is clearness parameter; $C_n = 1$ in one example of the book
k is the optical depth (there is a look-up table);

4 Assumptions

- $\beta < 45^{\text{o}}$

5 Steps

1. Find the (a_w, β) pair from $(-180^{\text{o}} < a_w < +180^{\text{o}},\ 0^{\text{o}} < \beta < 45^{\text{o}})$ to meet requirement:
    - reproduce solar noon shift observed from the tilted surface;
    - reproduce the true solar noon after correction;
2. Sort the pairs according to the difference between the corrected and the simulated I_h;
3. Pick the best pair which let the corrected I_h be as close as possible to simulated I_h.

Bibliography

Goswami, D., F. Kreith, and J. Kreider (2000), Radiation on tilted surface, in *Principles of Solar Engineering, Second Edition*, Taylor & Francis. 1, 3

Reda, I., and A. Andreas (2004), Solar position algorithm for solar radiation applications, *Solar Energy*, *76*(5), 577–589, doi:10.1016/j.solener.2003.12.003. 3

van As, D. (2011), Warming, glacier melt and surface energy budget from weather station observations in the Melville Bay region of northwest Greenland, *Journal of Glaciology*, *57*(202), 208–220, doi:10.3189/002214311796405898. 2